MICROMECHANICS OF ANISOTROPIC SOLIDS WITH DEFECTS AND INHOMOGENEITIES

FINAL PROGRESS REPORT

MARK KACHANOV

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Department of Mechanical Engineering
Tufts University
Medford MA 02155

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Prof. Mark Kachanov

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Tufts University
Medford, MA 02155

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12a. DISTRIBUTION / AVAILABILITY STATEMENT
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13. ABSTRACT *(Maximum 200 words)*

The research effort was focused on the mechanics of anisotropic solids with multiple cracks and pores. The most general case of arbitrary oriented and interacting defects was investigated. The following basic aspects of the problem were addressed: (1) the influence of anisotropy of the matrix on the mechanics of crack interactions; (2) effective elastic properties of anisotropic materials with multiple cracks; (3) mechanics of crack-microcrack interactions; (4) mechanics of anisotropic materials with multiple elliptical holes.

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1. Statement of the problem studied and summary of the most important results.

The research effort during the reporting period was focused on two main topics:

(I) The mechanics of anisotropic materials with multiple defects; and

(II) Stress concentrations and microfracturing patterns in materials with multiple defects, with applications to dynamic loading in long wavelength approximation.

More specifically, we addressed the following problems:

(a) *Mechanics of interacting defects in an anisotropic environment.* We analyzed the impact of material's anisotropy on the stress intensity factors at the tips of interacting cracks. We found that, of various elastic anisotropic moduli of the matrix, Young's moduli produce the highest impact on the mechanics of crack interactions, the shear moduli's influence is weaker and the effect of Poisson's ratios is very small.

(b) *Mechanics of crack-microcrack interactions.* We analyzed the impact of microcracks in the "process zone" on the main crack tip. This impact was found to be statistically unstable, fluctuating from stress shielding to stress amplification. Modeling of the process zone by a "weakened" homogeneous elastic material, often used in the literature, was found to be inadequate.

(c) *Anisotropic materials with multiple cracks.* This effort has been largely completed. Two main aspects of the problem were addressed: the effective elastic properties and the stress intensity factors at the tips of cracks in an anisotropic environment. It has been found that the said phenomena are strongly affected by the matrix anisotropy (particularly, by the anisotropy of Young's moduli; to a lesser extent, by the shear moduli and Poisson's ratios).

(d) *Dynamic loading ("undrained" response) of a fluid-saturated porous material.* Stress concentrations and fluid pressures induced by a dynamic loading of a porous material, in the long wavelength approximation, were investigated. We analyzed the cases when the pores are either dry or fluid filled. The resulting microfracturing patterns were examined.

(e) *Typical microfracturing patterns* in brittle materials with mixtures of interacting defects of diverse shapes have been investigated. The said patterns were found to depend on shapes of interacting defects and spacings between them.

(f) *Anisotropic materials with defects other than cracks* (pores of diverse shapes). We investigated the effective elastic response of an anisotropic material with defects of diverse shapes, using a mixture of elliptical holes of diverse eccentricities as a model. We obtained analytical solutions in the non-interaction approximation, which constitutes the basic building block for various approximate schemes aimed at accounting for crack interactions. The type of the overall anisotropy was investigated; it is found to be determined by symmetry elements common to the matrix anisotropy and a certain symmetric second rank tensor that characterizes the orientational distribution of defects. We analyzed in detail several important cases, like randomly oriented cracks, circular holes and cracks/holes mixtures.

2. List of all publications.

1. "Materials with Fluid-Saturated Cracks and Cavities: Fluid Pressure Polarization and Effective Elastic Response", with I.Tsukrov and B.Shafiro, *International Journal of Fracture*, **73**, pp. R61-R66, 1995.

2. "On the Concept of Approximate Elastic Symmetry with Applications to Materials with Defects", *International Journal of Fracture*, **74**, pp. R33-R38, 1995.

3. "Solids with Cracks and Cavities of Various Shapes: Effective Properties and Microfracturing Patterns", with I. Tsukrov, *Proceedings of the 26th Israel Conference on Mechanical Engineering,* Technion, Haifa, pp. 477-480, 1996.

4. "Stress Concentrations and Microfracturing Patterns in a Brittle-Elastic Solid with Interacting Pores of Diverse Shapes", with I. Tsukrov, *International Journal of Solids and Structures* , v. **34**, pp. 2887-2904, 1997.

5. Chapter "Mechanics of Anisotropic Materials with Multiple Cracks", with C. Mauge, pp. 3-46, in *"Key Engineering Materials"*, Transtech Publ., Switzerland, 1996.

6. "Three-Dimensional Interactions of a Circular Crack with Dipoles, Centers of Dilatation and Moments", with E.Karapetian, *International Journal of Solids and Structures*, **33**, pp. 3951-3967, 1996.

7. "Materials with Fluid-Filled Pores of Various Shapes: Effective Moduli and Fluid Pressure Polarization", with B. Shafiro, *International Journal of Solids and Structures,* v. **34**, pp. 3517-3540, 1997.

8. "Proper Parameters of Defect Density for Solids with Cracks and Cavities", in *"Proceedings of Symposium on Inelasticity and Damage in Solids Subject to Microstructural Change"* (in honor of the late Prof. L.M. Kachanov), in press.

9. "Three-Dimensional Interactions of a Half-Plane Crack with Point Forces, Dipoles and Moments", with E.Karapetian, *International Journal of Solids and Structures,* v. **34**, pp. 4101-4125, 1997.

10. "Solids with Cracks and Non-Spherical Pores: Proper Parameters of Defect Density and Effective Elastic Properties", *International Journal of Fracture*, in press.

11. "Effective Moduli of an Anisotropic Material with Arbitrarily Oriented Elliptical Holes", with I. Tsukrov, *Proceedings of the Royal Society of London*, Series A, submitted.

3. List of all participating scientific personnel.

1. Professor Mark Kachanov, Principal Investigator

1. Igor Tsukrov,
Ph. D. received in November 1995, later supported as a Research Associate.

2. Boris Shafiro,
Ph. D. received in May 1996, later supported as a Research Associate.

3. Edgar Karapetian, Ph.D., Research Associate.

4. Inventions.

None

5. Technology transfer.

The results of our work were implemented into the computer codes for dynamic fragmentation at SRI International (Menlo Park, CA). Our results were also implemented at

Schlumberger Research, Ltd. into the technology of interpretation of wavespeed patterns in anisotropic cracked geomaterials, in connection with oil exploration problems. Contacts were initiated with Dr. Rajendran (Army R&D) concerning development of codes for the dynamic fracture.

Scientific cooperation with two German Universities (Darmstadt Polytechnic Institute and Technical University of Munich) started; it is sponsored by von Humboldt foundation. Discussions concerning joint research effort were started with research divisions of Arco and Mobil. The PI was invited to make a comprehensive presentation at joint Arco-Mobil seminar (Plano, Texas).

Conference presentations:

1. International Conference "Numiform-95" (at Cornell University)
2. Symposium "Continuum Mechanics and Discrete Systems" (Varna, Bulgaria)
3. International Conference on Geomechanics, invited lecture (Vienna, Austria)
4. Workshop on Damage Materials, principal lecturer, 6 lectures (Fontenebleau, France)
5. European Geophysical Congress, Vienna, Austria.
6. ASME-SES-ASCE Meeting, Evanston, Il (two lectures).
7. IUTAM Symposium on Mechanics of Porous Materials, Cambridge, England.
8. Symposium on Poroelasticity, Ft. Lauderdale, Florida.
9. 7-th Annual Advanced Cement-Based Materials Computer Modeling Workshop, NIST, Gaithersburg, Maryland.
10. International Conference on Mechanics and Physics of Ice, Hanover, N.H.
11. Symposium on Inelasticity and Damage, St. John's, Canada (invited lecture).
12. U.S.Army Symposium on Solid Mechanics, Myrtle Beach, S.C.
13. ASME Annual meeting, Atlanta, GA (three presentations).

Seminars given:

1. Massachusetts Institute of Technology
2. Institute of Plazma Physics (Prague, Chech Republic)
3. Brown University

4. Schlumberger Research, Ltd.
5. Georgia Institute of Technology.
6. University of Erlangen, Germany.
7. Technical University of Munich, Germany (mini-course on micromechanics).
8. Darmstadt Polytechnic Institute, Germany.
9. Mobil & ARCO joint seminar, Plano, Texas.
10. Rensselaer Polytechnic Institute
11. Harvard University
12. Ecole Normale Superiuer, France
13. Ecole Polytechnique Federale de Lausanne, Switzerland
14. Aberdeen Proving Grounds

Miscellaneous:

Principal Investigator became an Editor of "*Letters in Fracture and Micromechanics*" and received von Humboldt's research award for senior scientists (Germany).

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Tufts University, Grants and Contracts Administration
Attn: Theodore M. Liszczak
Packard Hall, Room 103
Medford MA 02155

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